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RESEARCH DIRECTION IN INSTRUMENTATION AND CONTROL OF WATER AND WASTEWATER TREATMENT

by

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16. ABSTRACT

Instrumentation and automatic control, already common in oil, chemical and other industries, is making rapid strides in water supply and wastewater treatment systems. This report describes some of the capability now available and suggests directions for new research.

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Water and wastewater treatment and transport systems are cornerstones of economic development and effective environmental management in our modern society. Substantive resources are being applied worldwide to the development of these water and wastewater systems. As an example, since the creation of the U.S. Environmental Protection Agency in 1972, 40 billion dollars, have been appropriated at the Federal level in the United States to municipal wastewater treatment alone for construction of treatment plants.(1) These Federal funds have been matched by local capital contributions of nearly 10 billion dollars. As further perspective, an annual operating cost(2) of 5.3 billion dollars was spent in 1980 to support these municipal treatment systems. Indeed, an additional 118 billion dollars has been estimated as the capital costs(3) to complete (by the Year 2000) only the municipal wastewater treatment cornerstone.

Clearly in our complex world, effective use of these costly environmental cornerstones is essential for our physical and economic welfare. Their effective use also contributes important intangible benefits to the quality of life for ourselves and our neighbors. Our job, as environmental scientists and engineers, is, therefore, to pursue diligently the increasingly effective use of these cornerstones. Instrumentation and control is one link supporting that diligent pursuit.

We would like to share a perspective on how this pursuit is evolving in the Office of Research and Development of the U.S. EPA, specifically at the Water Engineering Research Laboratory in Cincinnati. To set the stage properly for that prespective, we need to consider very briefly the supporting state of the art in instrumentation and process control.

PROCESS CONTROL IN INDUSTRY

In industry, instrumentation and process control is nearly synonymous with automation. The use of automation and automated machinery for process control to improve productivity and reliability is in such an accelerated state of development that even the most visionary of our engineers and scientists may often underestimate its potential. In just the past decade, automation has made it possible to produce mechanical hands capable of picking up either eggs or lead bricks without breaking or dropping either. These same hands can be directed by other sensors to sort out flawed parts randomly scattered on a moving belt.

The oil industry is automated from the well-head through the refining process to the station pump that shuts off when your gasoline tank is full. The chemical, pulp and paper, steel and rubber industries are all automated. This automation has occurred without government funding, government guidelines, or any other type of government support. The delivery of processed water, though it is not as fully automated as the petrochemical industry, is also evolving into full automation. In the near future, even manual water meter readings are likely to be replaced by telemetered data.

These industries did not arrive at substantial automation in a single step, nor was automation set as an ultimate goal. The present level of automation in any industry is a result of careful analysis and multiple incremental refinements in process and control technology. Before any advances become state of the art, three things must occur: First, an understanding of the

problem is developed (often through the use of automatic measuring techniques). Second, automated control technology is applied to the problem. And third, the solution is proved to be cost effective.

The reading of water meters is an example of the incremental development process. Processing, transport, metering, billing, remote sensing and telemetering, and the processing of remotely sensed data are all present state of the art. Recent improvements in the technology of data transmission combined with the impact of inflation on wages and energy costs have unbalanced the existing cost-benefit equation. When it becomes profitable to read and transmit water use data automatically, the final link will be in place, and the market place will force implementation of this technology.

In the process industries, process control is not only extensively automated, but it has shifted from analog to digital control. The shift to digital control occurred not only because of improved control with digital systems but, more important, because it was more economical. The recent technical advances in minicomputers and digital process controllers (microprocessors) have produced major decreases in equipment costs per unit of control capacity. Thus in the classical control loop of sensor, controller, and actuator, a single inexpensive digital process controller or moderately expensive minicomputer can replace, respectively, a few or many analog controllers. In addition, the digital process controller or minicomputer permits an integrated approach to systems control.

In contrast to other industries, extensive integrated and automated system process control is just now penetrating the water and wastewater market.

Before addressing the use of instrumentation and automated process control to improve use of water and wastewater treatment systems, we will present a brief overview of the tools of automated process control in the water and wastewater field.

AUTOMATION AND INSTRUMENTATION IN WATER AND WASTEWATER TREATMENT

Classical process control theory and digital automation equipment have been fully capable of meeting the technical needs for automating water and wastewater treatment for the last 15 years. With the recent technical and economic improvements in digital process controllers, the capabilities of digital automation equipment now easily exceed the technical and economic requirements for automation of even small water and wastewater treatment plants. Indeed, digital process controllers, which are available for a few thousand dollars, contain sufficient control capacity to operate complete conventional water or wastewater treatment trains.

Though the capabilities of basic control theory and digital systems exceed the requirement of our water and wastewater treatment industries, sufficient sensors, satisfactory for most process control needs, have become available only in the last few years (Table 1). These sensors from selected manufacturers perform well with reasonable maintenance in the aqueous environment. The sensors and the tested process control loops (Table 2) now permit integrated automation of treatment plants and collection or distribution systems. Recent cost benefit analyses[4] have indicated a payback period of less than 3 years for the tested control loops.

Current use of these process control tools is limited even with their economic benefit. A key factor that may retard their increased use is the incomplete lack of knowledge of the dynamics of the treatment systems and the impact of those dynamics on receiving water and drinking water quality.

EMERGING INSTRUMENTATION AND CONTROL TECHNOLOGY

The perspective on automated control technology evolving in the Office of Research and Development may be conveniently divided into two areas: (1) emerging technology; and (2) a longer term overall systems engineering approach. We will first describe the emerging technology with its associated research and development needs and then integrate the elements of the technology into an overall systems engineering concept.

- Sensor Development and Improvement

Though sensor state of the art has advanced sufficiently to meet most of the pragmatic process control needs for our industry, a few key online sensors still need to be developed. An aqueous ozone meter, a viable bacterial sensor, and chlorate, chlorite, and chlorine dioxide sensors are needed for alternative disinfection processes. Toxicity sensors, total and specific volatile organic sensors, and improved total and specific soluble organic sensors are needed for toxics monitoring. A fluoride sensor and an economical corrosivity sensor is needed in water treatment, and a fuel content analyzer for wastewater sludge is useful for incineration.

TABLE 1. SUITABLE MONITORING SENSORS

Sensor	Type	Method	Interfaced to Microprocessor for process control
Total organic carbon	Continuous	Ultraviolet	no
Methane	Continuous	Thermoconductivity	no
Toxics	Continuous	Aerobic respirometry	no
Chemical oxygen demand	Discrete	Colorimetric	no
Carbon dioxide	Continuous	Infrared or thermoconductivity	yes
Nitrate nitrogen	Continuous	Colorimetric	yes
Halogenated organics	Continuous	Infrared	no
Adenosine triphosphate	Discrete	Spectrophotometric	no
Turbidity	Continuous	Light Scattering	yes
Suspended solids	Continuous	Light Scattering	yes
Flow	Continuous	Magnetic, mechanical, sonic	yes
Level	Continuous	mechanical, electronic, sonic	yes
Specific Probes*	Continuous	NH_4^+, NO_3^-, NO_2^-, metals	yes
pH	Continuous	Potentiometric	yes
Conductivity	Continuous	Amperiometric	no
Dissolved oxygen	Continuous	Galvanometric or Amperiometric	yes

*In some applications, interferences prevent satisfactory use.

TABLE 2. DEMONSTRATED PROCESS CONTROL LOOPS

Fully Tested Control Loops	Control Types	Microprocessor Software
Dissolved oxygen (air and pure O_2)	Feedforward with PID*, or GAP+ action feedback	yes
Flow	PID, or GAP action	yes
Sludge wasting	PID, or GAP action	yes
Sludge retention time	Continuous wasting Programmed GAP action	yes yes
Average food/mass ratio	Continuous wasting Programmed GAP action	yes yes
Thickening	GAP action	yes
pH	Feedforward with PID feedback	yes
Conductivity	GAP action	no
Chemical feed	Feedforward with PID feedback	yes
Chlorination	Feedforward with PID feedback	yes
Purging (NH_3 stripping)	Combined PID and GAP action	yes
Filtration	Logic network	yes
Carbon adsorption	Logic network	yes
O_3 disinfection	Feedforward with PID gas phase feedback	yes
Vacuum filtration	Logic network with PID	yes
Incinerator control	PID	yes

*PID is proportional, integral, derivative (feedback control).
+GAP action is on-off control (feedforward or feedback).

Of equal importance, the existing and new sensors can be significantly improved through accelerated development of direct digital sensing. The benefits of wide application of the emerging direct digital sensing approach include lower maintenance costs and improved confidence in the sensor measurement through self-diagnostics of sensor condition. The conversion of sensing from the classical analog measurement to the direct digital approach has potential cost and reliability benefits approaching those realized by conversion of analog controllers to distributed digital systems. In addition, the recently established North American Instrument Testing Service and its existing European counterparts offer improved quality control of the instruments and sensors for the industry.

- Monitoring of Treatment Process Streams

Continuous monitoring of process streams, especially the discharge streams from water and wastewater treatment plants, needs to be accelerated and adopted as an acceptable regulatory standard to improve plant compliance and to improve process control. Indeed, our Japanese colleagues routinely use continuous monitoring in their regulatory procedures. For example, the statistical relationship between continuous sensors (such as turbidity and soluble organic sensors) and the classical analytical measurements (suspended solids, BOD_5, and COD) have been established at several specific sites.[5] The continuous monitoring approach, especially with direct digital sensing, provides an economical method for improved compliance, particularly in small plants.

- Continuous Monitoring of Receiving or Supply Water Quality

Continuous remote monitoring capabilities for instream water quality with cost-effective data transmission to a central site is becoming a reality. The U.S. Geological Survey is now constructing a communication system through the Geostationary Orbiting Earth Satellite (GOES) for the 10,000 remote water monitoring stations in the United States. With the completion of that system, real-time management of surface water quality becomes possible. Lack of improved soluble organic sensors for remote operation, limit the realization of that management capability, however.

- Process Control and Treatment Reliability

Todays automatic control technology can achieve economic and energy benefits and improve operating reliability in the treatment plants and their collection or distribution systems. Emerging automated control technology can provide adequate control for managing gross contaminants and flows in most process applications and in the collection or distribution systems. However, we do not know enough about the treatment process dynamics, especially in wastewater treatment, and the instream dynamics of surface waters to use the treatment plants most efficiently or to realize the full potential of automated control technology.

The data acquisition and management capabilities of the digital monitoring and control tools are nonetheless increasingly powerful and economical. They enable us to gather the data needed to describe both process and instream dynamics, including variability and its causes or effects. This knowledge

permits improved design factors and operating approaches for our water and wastewater treatment and transport systems, thus reducing capital and operating costs.

One area that is not developed is practical monitoring and control of specific toxics and the generic toxicity of complex toxic mixtures in water. The lack of online sensors is a key limitation in this area. The evaluation of near real-time and real-time surrogate sensors for toxicity is now being initiated by the Office of Research and Development. Successful development of toxic monitoring and control remains a key deficiency in the emerging automated control technology.

THE SYSTEMS ENGINEERING APPROACH

The advanced control systems presented in this workshop are tools for establishing a systems engineering approach using water and wastewater treatment, and their collection and distribution systems. The systems engineering concept can be conveniently divided into three tiers:

- Centralized management of many automated municipal and industrial wastewater treatment plants and collection systems.

- Centralized management of automated drinking water treatment and distribution systems.
- Linkage of these water and wastewater management systems to the receiving water/water supply management system.

Limited integrated elements of the wastewater tier are in operation or have been planned at several locations. Metro Seattle is developing such an approach.[6] The EPA Office of Research and Development has also evaluated limited use of automated sensing to upgrade the circuit rider approach used for managing multiple small municipal treatment plants.[7] The Office of Research and Development is also beginning an automated compliance monitoring study of wastewater treatment including automated process control at its Test and Evaluation Facility in Cincinnati, Ohio. This study will also provide an improved understanding of the wastewater treatment process dynamics and causes of plant effluent variability. As I understand it, similar efforts are ongoing worldwide.[8] Though effective integrated centralized management of wastewater treatment and collection systems has not yet been realized, the elements for achieving this goal are clearly rapidly emerging.

Full automation of water distribution systems for both local and long distance transport have been state of the art for many years. Automated management of the water treatment systems is also available and with the microprocessor is affordable. A key deficiency in the centralized management of water treatment systems is, however, the lack of a real-time link between raw water supply quality and treatment plant operations. While early warning systems, such as those used by the Ohio River Sanitation Commission (ORSANCO)[9] and others[10,11] are being used to respond to massive spills of selected specific toxics, these responses are manually activated and are of limited scope. They offer limited protection to the consumer.

This then leads us to consideration of the third tier of the systems engineering concept. The third tier of the systems engineering concept, the linkage of our water and wastewater management systems to the receiving water/water supply management system are beginning to form within the U.S. Environmental Protection Agency. A major policy decision has been made to develop a water quality-based approach to control of toxics[12] in the United States. This will be an important catalyst for the development of the third tier.

The various elements of water and wastewater treatment systems dynamically interact with the receiving water/water supply system (Figure 1). The integrated systems engineering concept for the wastewater/receiving water interaction can lead to a number of improved and cost effective water pollution control management alternatives. These include:

- Improved understanding of the causes and the corrective control approaches for treatment plant performance variability and its effect on water quality.

- Improved approaches for multi-discharger wasteload allocation problems.

- More rational safety factors in wasteload allocation and treatment plant design.

- Improved management of the toxics and toxicity passthrough in wastewater treatment.

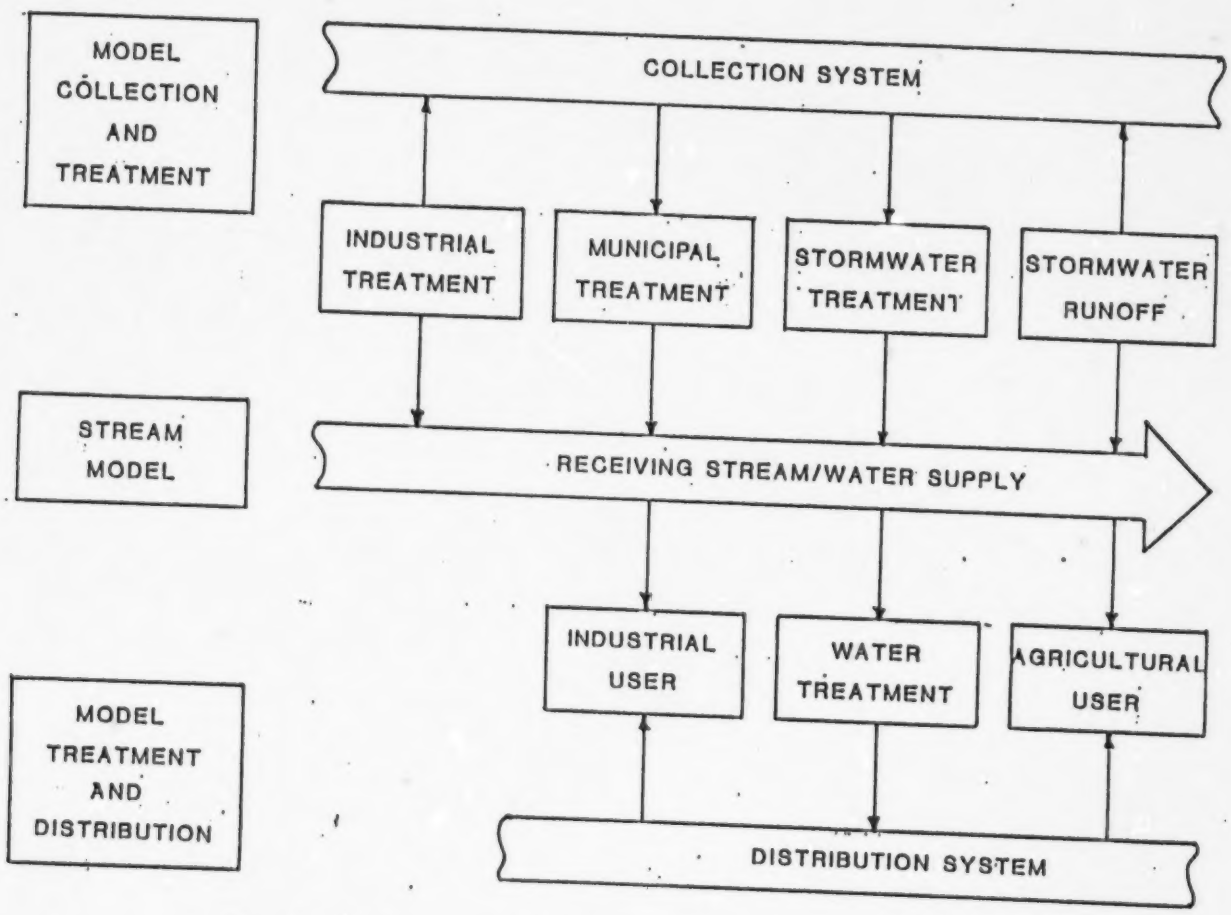

Figure 1. Components of the systems engineering concept.

- Improved strategies and tools for equitable, rational and cost effective municipal pretreatment programs and permits in toxics controls.

- Linkage of protocols for predicting pollutant removals and economic analysis protocols for assessing least cost solutions to water quality management.

In the wastewater/water supply/water treatment interaction, the integrated systems engineering concept addresses the important issue of the impact of wastewater discharges on the drinking water quality. The Office of Research and Development has supported research to characterize surface water quality[13] and to develop surface water quality models[14] for assessing the impacts of normal effluent discharges and pollutant spill on water quality for the lower Mississippi River. The primary emphasis is on the movement of organics within the river and the effect that discharge policies under varying hydrologic conditions can have on the concentrations of residual toxics at raw water supply intakes. The implications for the water and wastewater treatment industries are substantive.

In concluding, our evolving systems engineering approach promises the tools for equitable solutions to such problems. The interactive models for improved water quality management approaches will initially involve predictive methods developed from data gathered by your automated instruments, monitoring

and process control technology. With data transmission tools such as the U.S Geological Survey's satellite system, the evolving concepts could even ultimately approach closed-loop operations in water quality management. The challenge to all of us is to pursue efficiently the development of these concepts and thus more effectively use our water and wastewater treatment resources.

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